How Nanotechnology Addresses Portable Power Market Issues

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Booth 329

. . . power from nanotechnology

  - Laptops (i.e., ~10,000mAh and down)
  - Does not include transportation
  - Does not include portable generators
- Batteries and tech advances
- Portable power market overview
- Nanotechnological advances in portable power
- Future power possibilities
  - Fuel cells
  - Ultracapacitors
  - Solar
- Summary

1981 Single sided floppy
160KB (5.25” sq/flat)

2007 Flash / thumb drive
16 GB / (~3”x3/8”x3/4”)

IMPROVEMENT: ~100,000x in ~25 years

1961 DEC PDP-1
200 KHz magnetic processor

2007 HP Pavillion PC
2.1 GHz processor

IMPROVEMENT: ~10,500x in ~45 years

1950 NiCad Battery
45 to 65 Wh/kg

2007 Li Ion battery
100 to over 300 Wh/kg[1]

IMPROVEMENT: ~6.5x in 50+ years

In fact, in the last 100+ years, one writer[2] calculates that batteries have only improved a total of 8x

1– Energy density data is from a number of sources, primarily Isidor Buchmann, *Batteries in a Portable World*, 2nd Ed. Canada: Cadex Elcetronics, 2001; and T.R. Crompton, *Battery Reference Book*, 3rd Ed. Oxford, UK: Reed Educational and Professional Publishing Ltd., 2000.
2 -- John Hockenberry, “Building a Better Battery”, *Wired Magazine*, 11/2006

Batteries and tech advances

- Moore's Law (ca 1965)
  - Electronic technology performance doubles every 18-24 months
  - Nanotechnology provides opportunity to reach fundamental / atomic limits of Moore's Law
  - Moore (2005): 10 or 20 years before we reach that limit[1]
- Batteries not keeping pace
  - Most practical active materials have been investigated and
  - List of unexplored materials is being depleted[2]

1 – Manek Dubash. "Moore's Law is Dead Says Gordon Moore", *Techworld*, 13 April 2005
2 – David Linden and Thomas Reddy. *Handbook of Batteries*, 3rd Ed. New York: McGraw-Hill 2002, p 1.6

Batteries and tech advances

Why?

Batteries

Same technology; different chemistries

- chemical reaction creates current
- new chemistries bring performance improvements

Data storage

New technologies

- magnetic
- optical
- flash drives

BUT . . .

should we care?

Isidor Buchmann, *Batteries in a Portable World*, 2nd Ed. Canada: Cadex Electronics, 2001.

Batteries and tech advances

- Can there be significant improvement (short of a new paradigm)?

2 points of view
POV 1: NOT MUCH

  – Laws of physics (“storing electrons chemically takes space and weight”)[1]

1 – John H. Reif and John Monahan, “Introduction”, *NSF Workshop: Emerging Opportunities of Nanoscience to Energy Conversion and Storage*, Arlington, VA: National Science Foundation, 21-22 November 2005

Batteries and tech advances

- Estimated 25% of volume currently utilized[1]
- Table comparing theoretical to practical specific energy[2]

			Wh/kg		
Battery type	**Anode**	**Cathode**	**Theoretical**	**Practical**	**% usage**
Alkaline	Zn	MnO_2	358	145	41%
Zinc air	Zn	Air	1353	370	27%
$LiMnO_2$	Li	MnO_2	1001	230	23%
Lead acid	Pb	PbO_2	252	35	14%
Nickel metal hydride	MH	Ni Oxide	240	75	31%
Nickel cadmium	Cd	Ni oxide	244	35	14%
Lithium ion	Li_xC_6	$Li_{(i-x)}CoO_2$	410	150	37%

1 – John H. Reif and John Monahan, “Introduction”, *NSF Workshop: Emerging Opportunities of Nanoscience to Energy Conversion and Storage*, Arlington, VA: National Science Foundation, 21-22 November 2005; Greg Eyring, “Summary of the Power Systems Workshop on Nanotechnology for the Intelligence Community”. Washington, DC: National Academies Press, 2003

2 – Table source: David Linden and Thomas Reddy, *Handbook of Batteries*, 3rd Ed. New York: McGraw-Hill, 2002, pp 1.12-1.13

Batteries and tech advances

- Can there be significant improvement (short of a new paradigm)?
  - Could get 50% to 75% with:[1]
    - Better structures
    - Improved surface area

1 – Greg Eyring, “Summary of the Power Systems Workshop on Nanotechnology for the Intelligence Community”. Washington, DC: National Academies Press, 2003

Batteries and tech advances

- Can there be significant improvement (short of a new paradigm)?

2 points of view
POV 2: YES

  - New materials continue to improve performance[1]
  - Some claim 5x to 10x improvements over Li Ion[2]

1 – Donald R. Sadoway, *Fuel cells and portable pow*er solutions (video of lecture at MIT Museum), Cambridge, MA: MIT, February 21 2006
2 – patent by NanoGram; A123 Systems

Portable power market overview

- Areas for improvement:
  - Energy / power densities (mobile soldier – 20% wt = battery)[1]
  - Battery life[2]
    - Laptops: 2 - 3 hours; need 8 - 12 hrs[3]
      - 2nd most common complaint about laptops [4]
      - Dell: New Vestro notebooks "up to 7.41 hours"[5]
    - Cell phones: avg 4 - 5 hours; need 8-12 hours[6]
      - 2nd most common complaint about cell phones (first is call quality)
      - Some achieve over 8 hrs, but trade-off in other functions / display quality, etc.
    - Multi-functional devices require longer life
    - Recharge speed and cycle number

1 –Michael Sinkula, *Micro Power Sources: Opportunities from Fuel Cells and Batteries for Mobile Applications. Glen Allen, VA:* NanoMarkets, LC, September 2005
2 – Ibid., interviews with OEMs and battery mfrs.
3– Leroy Olsen, "Silicon-Based Micro Fuel Cells for Mobile Electronic Applications", *Micro/Nano Breakthrough Conference.* Portland, OR: Neah Power Systems, July 28 2004
4 – Ibid.
5 – Ad from Dell rec'd 24 Sep 2007
6 – From CNET testing of 403 cellular phones; results published 2 July 2007 at http://reviews.cnet.com/4520-11288_7-6634891-1.html

Portable power market overview

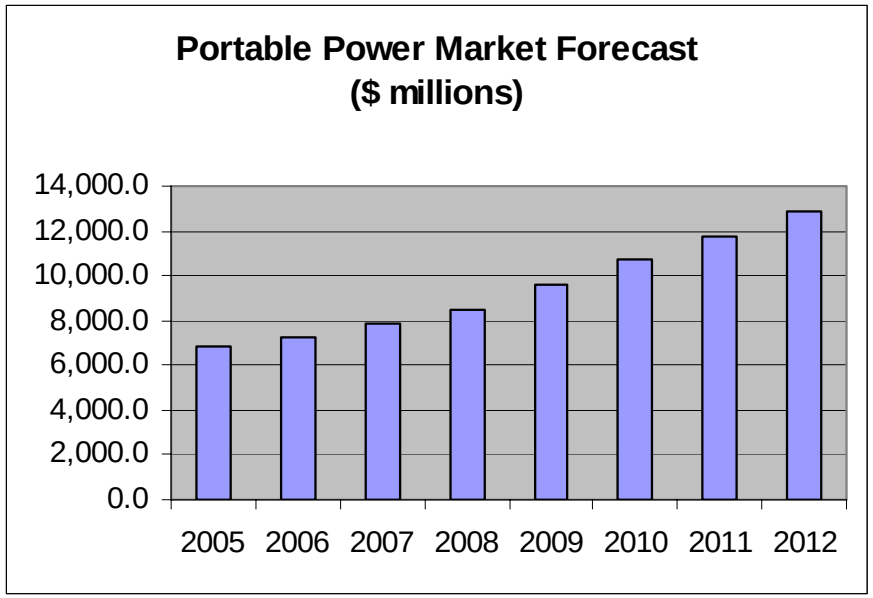
- Costs
  - Consumer acceptance varies by application
    - Microbatteries:
      <$0.025 / mAh initially;
      ~$0.005 / mAh in production
    - Laptops
      (currently anywhere from $0.011/mAh to $0.075/mAh)

Portable power market overview

- New market segments coming:
  - Microbattery devices
    - “Smart” cards
    - Remote sensors
    - RFID tags
    - On-chip devices
    - and many more

Portable power market overview

- Total mobile power sources:



. . . a large and growing market

Sources: Michael Sinkula, *Micro Power Sources: Opportunities from Fuel Cells and Batteries for Mobile Applications. Glen Allen, VA:* NanoMarkets, LC, September 2005; and interviews with OEMs and battery mfrs.

Portable power market overview

The big question:

Are the potential advancements in materials science adequate?

Government-funded Fuel Cell Group: NO

University-funded Material Scientist: YES

What a shock 

What Can Nanotechnology Do?

- Surface area improvement (nanoparticles / nanowires)
  - NanoGram[1]
    - Vanadium oxide nanoparticles
    - May 2007 Patent 7214446 claims specific energy 950-1200 Wh/kg; (could find no reference on power densities)
  - Enable IPC Corp[2]
    - Nanowire electrodes
    - Seeing greater power densities
  - JPL / CalTech[3]
    - Nanowire electrodes
  - MIT[4]
    - Self-assembling nanowire electrodes

1 – NanoGram patent 7214446 as printed at http://www.patentstorm.us/patents/7214446-claims.html
2 – Unpublished data from S.H. Choi, Ph.D. and M.A. Daugherty, Ph.D., Enable IPC Corporation
3 – W.C. West, et.al. "Electrodeposited amorphous manganese oxide nanowire arrays for high energy and power density electrodes", *Journal of Power Sources*, 1 August 2003
4 – "Researchers employ viruses to build tiny batteries", *MIT TechTalk*. April 12 2006

Nanotechnological advances

- Life extension
  - mPhase (AlwaysReady – created in April 2007 to address nanobattery product)[1]
    - Nanowires enable a “switch on” battery
    - NASA Tech Briefs “Nano 50”
    - Frost & Sullivan Excellence in Technology Award
- New materials
  - Altair (lithium titanate spinel oxide nanocrystals -- NanoSafe)[2]
  - A123 Systems[3]

1 – “mPhase Technologies launches nano/MEMs company, AlwaysReady”, *Small Times,* April 18 2007on http://www.smalltimes.com/articles/article_display.cfm?Section=ARCHI&C=Elect&ARTICLE_ID=290195&p=109
2 – Wolfe, Josh. “Altair: Nano Pretender No More”, *Forbes/Wolfe Nanotech Report*, April 5 2007
3 – “Revolutionary New Nanotechnology Based Lithium Ion Battery”, *Nanotechnology News*, November 3 2005

Nanotechnological advances

What do we really need?

Not a lot more

- Laptops last 3 hours; need 8–12 hours (a 3x–4x improvement)
- Enhanced cell phones last 2–8 hours; need 8–12 hours (a 1.5x–4x improvement)
  - July 2 2007 CNET announced testing of cell phone battery results
- Microbattery: “Smart” cards need 2 years
- But the bar keeps shifting
  - More functionality drains newer batteries
  - Tough to keep up
  - Some of the improvements are in power management, which helps batteries

Future power possibilities

Prediction is very difficult,
especially about the future.

Niels Bohr
Danish physicist & Nobel Laureate

Future power possibilities

Is materials science enough?

Some say yes – <battery improvement in the past few years, esp. with nanotech, seems like it could keep up>

Some say no – <there are physical limits to what can be accomplished in terms of materials>

The answer is . . .

Future power possibilities

Yes, for the near term; but we must continue to look for the quantum leap

Future power possibilities Ultracapacitors

- Improve power
  - Fast recharge / discharge
- Improving energy storage (for some applications)
- Combined with batteries
  - Decreases wear and tear on batteries
  - Cellular phones
    - CAP-XX
- In the hunt:
  - UW / EIPC / SolRayo
    - Nanoparticles
  - MIT
    - Nanotubes
  - EESTOR (automotive)
  - Others . . .

Future power possibilities
Fuel Cells

Energy density comparisons

- Li-Ion theoretical: 1400 Wh/L; commercial: ~250 Wh/L (~18%)[1]
  - Some R&D with better results
- DMFC theoretical: 4800 Wh/L; at 18% = ~864 Wh/L[1,2]
  - Today, portable fuel cells (in lab) can produce about 500 Wh/L[3]

1 – DARPA BAA 07-21, Addendum 6, 2007; Alan Soucy, "An improved power solution for portable electronics", *MTI Micro Fuel Cells*, 6th Ajnnual International Symposium, Small Fuel Cells, 2004

2 – Kenneth Lux, *Nano-scale fuel cells may be closer than we think*, Kenneth Lux, physorg.com news, 21 Mar 2006

3 – Michael Sinkula, *Micro Power Sources: Opportunities from Fuel Cells and Batteries for Mobile Applications*. Glen Allen, VA: NanoMarkets, LC, September 2005

Future power possibilities
Fuel Cells

- Nano-enabled fuel cells
  - 3D structures increase surface area (UW)[1]
  - PEM nanoparticles increase surface area (MPI)[2]
  - Ceramic nanopowders for SOFC (solid electrolyte membranes improve ion conduction and thermal stability) [2]
  - H2 storage (nanocrystalline metal hydrides, e.g.)[2]

1 – Kenneth Lux, *Nano-scale fuel cells may be closer than we think*, Kenneth Lux, physorg.com news, 21 Mar 2006
2 – Dr. Wolfgang Luther. “Fuel cells – Potential applications in space and nanotechnology methods for improving fuel cells”. *The A to Z of Nanotechnology*, 2007 on http://www.azonano.com/details.asp?ArticleID=1123

Future power possibilities
Fuel Cells

- By 2010, portable fuel cells for consumer markets are projected to produce 1,000 Wh/L[1]
- Economic viability?
  - Pt / fuel availability
  - Pacific Fuel Cell
- Consumer acceptance?
- Fuel availability/infrastructure?

1 – *Fuel Cells Sub-Program Overview*, DoE, 2006; *Proceedings of the Fuel Cells for Portable Power Workshop*, January 15-17 2002

Future power possibilities
Solar

- Solar cell “paint” / plastics
  - Nanorods / plastic electronics “painted” on the back of a device that recharges battery (UC Berkeley)[1]
  - Kararka – paintable solar plastics[2]
  - Integrated into fabrics[3]
  - Roll-out plastic sheets[3]
- Cost issues[1,2,3]

1 – Justine Brown. “New Generation of Solar Cells Combines Nanotechnology with Plastic Electronics to Recharge Portable Devices”. *CIO*, 15 August 2002
2 – Olga Kharif. “Ultraportable Power Charges Ahead”. BusinessWeek, September 20 2005
3 – Stefan Lovgren. ”Spray-on Solar Cells Are True Breakthrough”. *National Geographic News*, January 14 2005

Summary

- Battery development lags behind
  - 2x to 10x improvement possible; maybe more
  - Sufficient for some time
- Looking for the quantum leap
  - Ultracapacitors?
  - Fuel cells?
  - Solar or other?

Summary

Likely a combination of technologies

- Applications specific
- Economic tolerance
- Performance factors
- Consumer acceptance

Thank you!

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